PHOTOMASK

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Effective-exposure-dose monitoring technique in EUV lithography

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ABSTRACT

EUV lithography is a promising candidate for 2x-nm-node device manufacturing. Management of effective dose is important to meet the stringent requirements for CD control. Test pattern for a lithography tool evaluation, the effective dose monitor (EDM), shows good performance in the dose monitoring for optical lithography, for example, KrF lithography. The EDM can measure an exposure dose with no influence on defocus, because the image of an EDM pattern is produced by the zero-th-order mask shadowing effect should be taken into consideration. We calculated the shadowing effect as a function of field position and applied it to correction of the experimental dose variation. We exposure field to be 2.55 % when corrected by the shadowing effect. We showed that the EDM is lithography.

1. Introduction

In the manufacture of ULSI devices, pattern shrink cuts cost and reduces power consumption. An EUV lithography tool is expected to be employed for 2x-nm-node device manufacturing and beyond. In order to meet the stringent requirements for CD control, management of both the ef-

Continues on page 3.

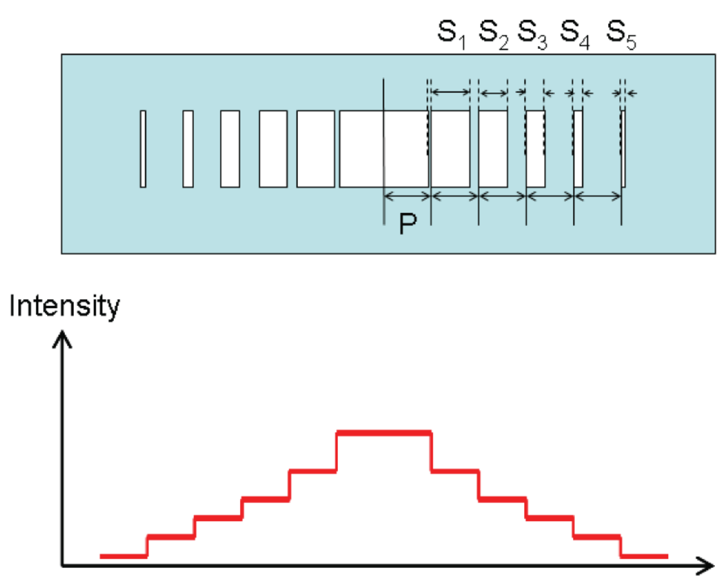

Figure 1. The design of bar-type exposure dose monitor. Intensity depends on the duty ratio S_i/P.

EDITORIAL

EUV Mask Inspection: Removing or Adding Roadblocks?

By **Artur Balasinski,** Cypress Semiconductor Corp.

As if pursuing EUV lithography was not hard enough due to the process challenges, it is also EUV paraphernalia, such as mask metrology and inspection, that present costly issues by themselves. Equipment makers are making bets, which option to commit to for EUV mask inspection: e-beam or actinic. At stake are amounts from $200 to $400 million, which, while looking pale compared to the billions already spent, are still large enough for IBM, Intel, Samsung and TSMC to think twice about, before handing them over to Sematech, Applied Materials and KLA-Tencor to build the equipment without delaying the 2012 schedule for the stepper delivery.

For many years, inspection was part of maskmaker's holiday: it was carried out on resist pattern on wafer by an optical tool. But geometry shrinks required detecting ever-smaller defects and a high resolution electron beam was called for. However, scanning electron microscopy takes up to 100 times longer than a laser beam to inspect a mask and also charges up the photoresist. As a result, Cost-of-Ownership of e-beam inspection system has surpassed the one of e-beam writers at the 90-nm node. But then, further investment strategy depended on the directions for Next-Generation-Lithography (NGL).

Companies going fabless or taking advantage of analog design capabilities at 90 nm were mostly interested in cost reduction of the existing e-beam systems. But for the shrink path leaders, mask inspection had to be closely associated with the NGL. Unlike masks for immersion, double exposure, advanced OPC, and Source-Mask-Optimization, the EUV may take advantage of the alternative and attractive actinic inspection at the scanner wavelength. However, development of the actinic inspection has to look at the progress of the EUV: one cannot exist without the other. For as long as the EUV remains a 22-nm front-runner, as stipulated by the recent orders for 6 initial NXE-3100 and 10 more NXE-3300 full production ASML tools at up to $100M a piece, actinic inspection looks like a safe bet.

Or is it really safe? While the EUV momentum trajectory needs to be confirmed, removing the inspection roadblock by the actinic methodology may not be required as existing inspection tools, such as KLA-Tencor's 6xx, could handle many of the initial chores in detecting EUV mask and blank defects. The e-beam lab setup demonstrated the feasibility, with increased sensitivity at small absorber pitches. A DUV laser may be needed as complementary to detect the relatively small number of defects missed by an e-beam or optical mask inspection.

So to some, more funding for the next-generation inspection looks as an extra roadblock added to the list of still unresolved EUV issues, such as the need for higher power, acknowledged by ASML even as their first tools are slated to be delivered already by 2012. For that reason, KLA-Tencor and Sematech are still asking for funding while trying to spin some movement on the EUV metrology and inspection front. The fears that the EUV scanners would be ready for production at the designated time, but there would be no metrology tools to support because the inspection vendors have been dragging their feet, are being dispelled. But the R&D funding and return-on-invest remains a question for both EUV and its metrology. We will continue addressing this question in the upcoming issues of BACUS Newsletter; stay tuned.

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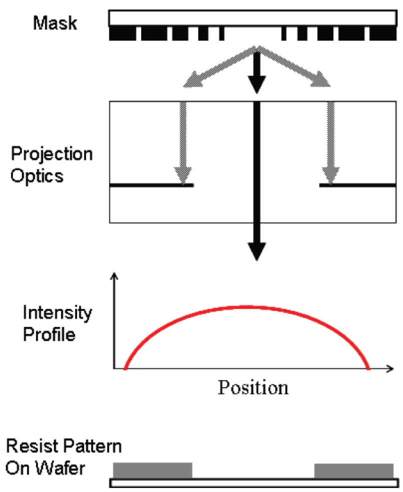

Figure 2. The principle of the exposure-dose monitor.

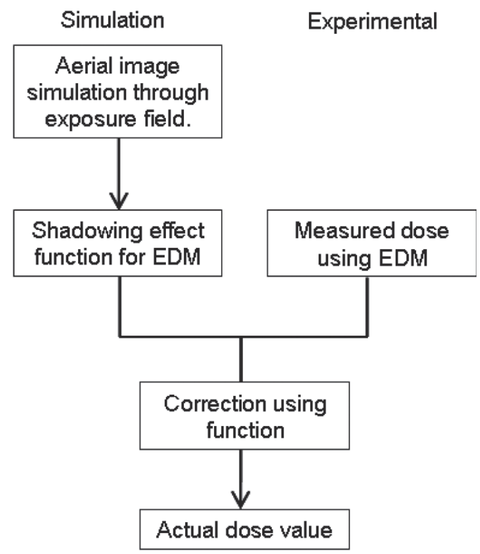

Figure 4. Dose correction flow of this study.

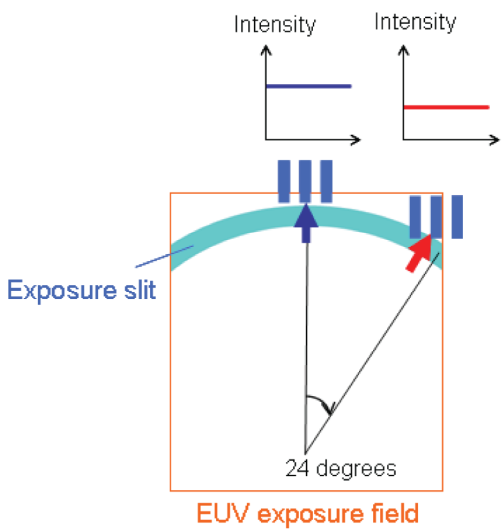

Figure 3. The shadowing effect for EDM depends on azimuth.

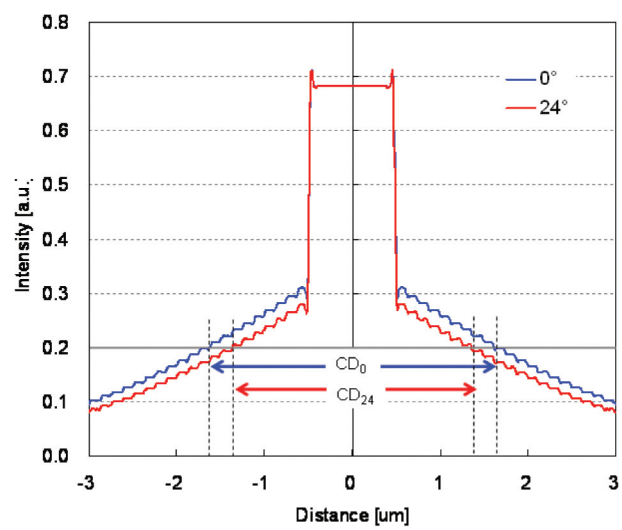

Figure 5. Aerial images of exposure dose monitor at azimuths of 0° and 24°.

fective dose CD control is based on the use of a dose monitoring mark, named the effective exposure dose monitor (EDM). The EDM has shown good performance for dose monitoring in in-line optical lithography.[1] We improved process window of KrF lithography using the EDM technique.[2,3] It is also expected to be useful in EUV lithography evaluation. We measure the effective exposure dose in EUV lithography using bar-type EDM.

When applying an EDM technique to EUV lithography, the mask shadowing effect should be considered.[4,5] For the off axis incidence of illumination to a reflective mask, the absorber pattern shades a part of the ray. And then, the amount of energy contributing to the imaging on a wafer is reduced. We call this the "mask shadowing effect". The mask shadowing effect has theoretically been anticipated.

In this work, we applied the EDM to EUV lithography. We employed a bar-type EDM shown in the following section for the mask pattern and used a 3D rigorous simulation for the calculation. In an experimental, we measured the dose variation of EUV lithography tool. Applying the shadowing effect correction to the experimental dose variation, we obtained an actual dose variation through an EUV exposure field.

2. Effective-exposure-dose monitor

2.1 Theory

A bar-type effective exposure dose monitor (EDM) is designed based on the concept of Starikov's exposure monitor.[5] The EDM pattern consists of gradation grating. The pitch P of the grating is constant, but the duty decreases from the center to edge (Fig. 1). Since the pitch P is shorter than the resolution limit of the exposure tool, the individual lines do not resolve on a wafer, which is, restricted by the following equation.

$$P \leqq \frac{\lambda}{NA(1+\sigma)} \qquad (1)$$

where λ is the wavelength of exposure light, NA is the numerical aperture of the projection optics at the wafer side and σ is the coherent factor. The exposure light is diffracted by the mask with a diffraction angle $\sin^{-1}(\lambda/P)$. When the pitch P satisfies the eq. (1), positive and negative first-order diffraction ray cannot enter the

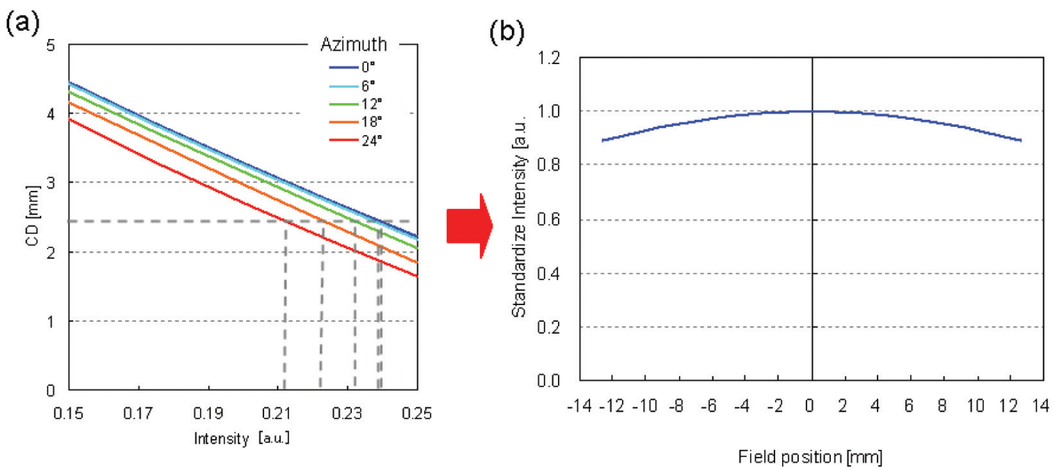

Figure 6. (a) The relation ship between CD and intensity at various azimuths. (b) Shadowing effect function depending on field position.

Table 1. Lists of simulation conditions.

Simulator		Sentaurus Lithography (Synopsys)
Projection condition	NA	0.25
Illumination condition	Figure	circle
	σ	0.5
Wavelength		13.5 nm
Incident angle at mask		6 degree
Flare		none
Azimuth		0-24°
Mask Absorber thickness		61nm
Multilayer material		Mo/Si
Number of multi-layers		80 (40 pairs)

pupil because of the wide angle of diffraction. Figure 2 illustrates the mechanism of this theory. Due to the diffraction limit, only the zero-th-order ray, whose intensity depends on the duty ratio, can reach a wafer. The change of duty ratio gives an intensity profile as a function of the position at the wafer. Since only the zero-th-order ray provides this intensity profile, it does not depend on focus. In this study, the pitch P must be smaller than 36 nm (λ = 13.5 nm, NA = 0.25, σ = 0.5).

In the manufacture of ULSI devices, pattern shrink cuts cost and reduces power consumption. An EUV lithography tool is expected to be employed for 2x-nm-node device manufacturing and beyond. In order to meet the stringent requirements for CD control, management of both the effective dose and the effective focus is essential. Our approach to CD control is based on the use of a dose monitoring mark, named the effective exposure dose monitor (EDM). The EDM has shown good performance for dose monitoring in in-line optical lithography.[1] We improved process window of KrF lithography using the EDM technique.[2,3] It is also expected to be useful in EUV lithography evaluation. We measure the effective exposure dose in EUV lithography using bar-type EDM.

2.2 Problems concerning EUV mask

We use the EDM for evaluation of the dose uniformity of lithography tool. When we apply this technique to EUV lithography, a mask shadowing effect causes variation of the EDM sensitivity and depends on position. The quantity of the effect of shadowing on image width depends on oblique incidence and azimuth. As shown in Fig. 3, effective duty ratio of lines and spaces differs depending on azimuth at the same mask size. The intensity profile of the EDM is determined with duty ratio changes of lines and spaces from center to edge of the pattern. Therefore, the EDM sensitivity is also affected bye the shadowing effect depending on field position.

We estimate the mask shadowing effect value for EDM sensitivity by mask 3D simulation. We apply shadowing effect correction for dose measured by EDM. Figure 4 shows the flow of this correction.

3. Simulation condition

We used Sentaurus Lithography (Synopsys) for 3D topography simulation. The simulation conditions are shown in Table 1. The pitch P of effective-dose monitor pattern in this study is 31 nm.

4. Results and Discussion

4.1 Dose monitor CD change depends on azimuth in simulation

Figure 5 shows simulation results, namely the aerial images of EDM at azimuths of 0° and 24°, which correspond to the center and edge of EUV exposure field, respectively. Even if both positions are the same in intensity, the CD of the EDM differs depending on azimuths that indicate field position.

We also calculated the aerial images of an EDM at azimuths of 6°, 12°, and 18°. We calculated CD changes of the EDM on a wafer depending on intensity from aerial image. Since intensity corresponds to exposure dose, CD of EDM changes depending on exposure dose. Figure 6(a) shows the relationship between the CD and intensity at various azimuths. This graph shows that the exposure dose value indicated by the same CD differs owing to the shadowing effect. Azimuth corresponds to field position. For example, the field center receives EUV light as azimuth of 0°, whereas the field edge is receives it as azimuth of 24°. Figure 6(b) shows that a certain CD of EDM indicates different intensity depending on field position.

We obtained a function of shadowing effect depending on field position, as Fig. 6(b). We apply these simulation results to measure dose uniformity of an actual EUV exposure tool.

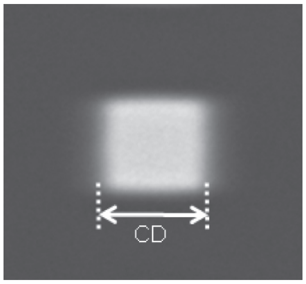

Figure 7. The measurement image of EDM by Acher 200. Black area is covered by resist, and white is clear area.

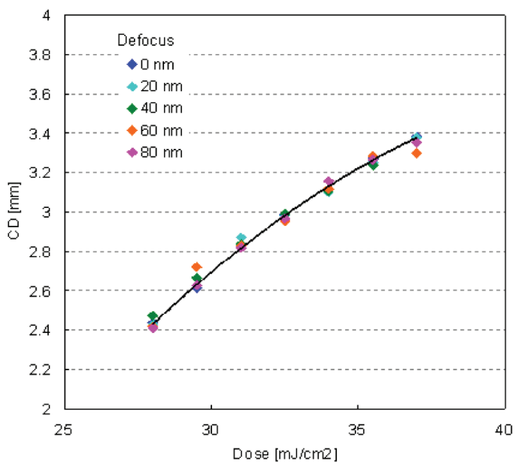

Figure 8. Actual dose monitor CD changes depending on dose (tool indicated).

Table 2. Lists of experimental conditions.

Illumination condition	NA 0.25 / circle / sigma 0.5
Resist thickness	80 nm
CD measurement tool	Archer 200 (KLA-Tencor)
CD measurement tool	Archer 200 (KLA-Tencor)

4.2 Dose uniformity measurement for EUV tool using EDM

The experimental conditions are shown in Table 2.

Figure 7 shows an EDM image captured through an objective of the CD measurement tool. Fig. 8 shows CD of EDM depends on the exposure dose that the tool shows. It is measured at the identical position (field center) of each exposure field. This graph indicates that the sensitivity of EDM does not depend on defocus and the EDM functions.

We measured CDs of EDM at various of positions in the exposure field. Figure 9 shows a dose distribution through the field converted from measured CD. The dose variation in this graph is 9.94 %. However, this result includes the mask shadowing effect depending on field positions. We corrected the measured dose variation using the shadowing effect function we obtained. The corrected result is shown in Fig. 10. This graph shows the effective exposure dose variation. We obtained effective exposure dose variation through the EUV exposure field as 2.55 %.

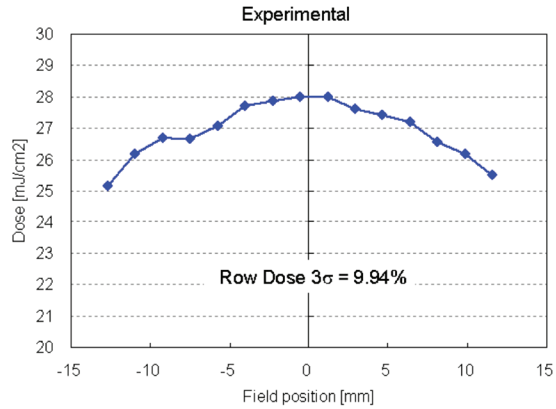

Figure 9. The measurement results of EDM include a mask shadowing effect depending on field positions.

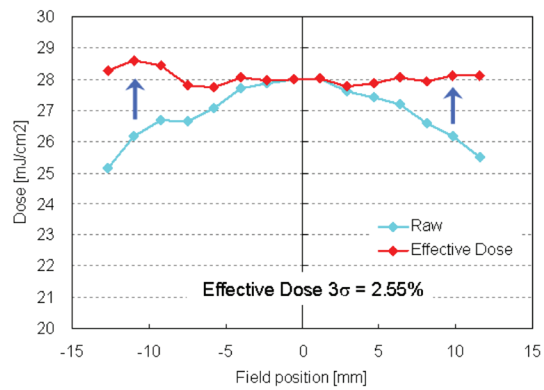

Figure 10. Effective exposure dose variation excluding shadowing effect.

5. Conclusion

In this paper, we studied the effect of shadowing on image width through the EUV exposure field in the case of using the exposure-dose-monitor (EDM) technique. We calculated the effect of shadowing as a function of field position and applied it as a "correction" to the experimental dose variation. We measured the dose variation through EUV exposure field as 2.55% when corrected by the shadowing effect. The EDM technique is also applicable in EUV lithography management.

This dose variation includes the influences of mask error and flare. A subject for future work is estimation of these influences on EDM in the case of using dose management in manufacturing.

6. Acknowledgments

This work was performed by the Research Alliance Teams at various IBM Research and Development Facilities.

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Industry Briefs

Sematech and Zeiss Tool to Measure EUV Mask Defects

By **Mark Osborne,** Semiconductor

Sematech and Carl Zeiss announced an agreement to design and develop the industry's first-ever actinic aerial image metrology system for defect review of EUV photomasks. The AIMS EUV tool is critical for defect-free extreme ultraviolet lithography masks targeted at the 22 nm technology node and beyond. Production-worthy version of the platform is scheduled for early 2014, in line with the expected introduction of EUV lithography into high-volume manufacturing by 2015, according to Sematech. In collaboration with Sematech's EUVL Mask Infrastructure (EMI) consortium, Carl Zeiss will investigate a concept and feasibility plan for a tool that emulates the aerial image formed by a EUV lithography scanner supporting the 22 nm half-pitch node requirements with extendibility to the 16 nm HP node. The EMI was launched in February 2010 to develop critical metrology tools, considered too costly for individual companies to develop independently. It addresses the metrology gap by funding the development of three metrology tools for detecting and assessing defects in advanced masks needed for extreme ultraviolet lithography. The first phase will focus on enabling an enhanced EUV mask blank inspection capability by 2011, followed by development of an AIMS for EUV in 2014 in collaboration with Carl Zeiss, and finally a EUV mask pattern inspection tool able to work at 16 nm HP by 2015. The EUV masks used for sub-22 nm patterning must be free of defects to avoid transferring them onto chip circuits—but current metrology tools are generally ineffective at finding defects below 32 nm node requirements.

EUV Litho Sources Improving, says Workshop

By **Peter Clarke,** EE Times

Sources for extreme ultraviolet lithography are not yet sufficiently bright to allow commercial wafer throughputs, but they are improving sufficiently for beta tools shipping in 2011, according to participants at a workshop held in Maui, Hawaii. "Although scanner throughput needs improvement, the remaining specs for beta scanners are expected to be met," said Vivek Bakshi, organizing chair of the workshop and president of EUV Litho Inc. (Austin, Texas). Based on the present data, it appears that 40-watt sources will be available this year and 60-watt next year for integration in the beta scanners. These sources should provide sufficient throughput for beta scanners to allow chip-makers to develop processes for high volume manufacturing. During the workshop ASML (Veldhoven, The Netherlands) announced it has received six orders for its NXE:3100 beta scanner, and plans to ship the first tool this year and the others in 2011. The first tool is expected to go to the IMEC research institute. Jos Benschop, vice president of research at ASML, said his company is looking at multiple suppliers of both laser produced plasma (LPP) and discharge produced plasma (DPP) technologies for EUV sources for beta scanners. "EUV offers the best balance between cost, shrink and absence of design restrictions," said Benschop, in a statement issued by EUV Litho. Discussion on EUVL sources dominated the meeting including details from supplier Gigaphoton of a source offering 104-watt power at intermediate focus. The company expects to increase source lifetime through improved thermal-load handling. The source currently offers 2.5 percent conversion efficiency, 7.9-kW CO2 laser operation, 20 percent duty cycle, 1.04 millijoules pulse energy at IF with a 100-kHz operation frequency. Next-generation EUV sources are expected to have wavelengths shorter than the current 13.5-nm. Padraig Dunne of University College Dublin (UCD) spoke of LPP-produced terbium and gadolinium plasmas as EUVL sources with wavelengths of between 6.5-nm and 6.7-nm. If multilayer reflectivity at these wavelengths is low and higher power density is needed to produce the plasma at these wavelengths, another wavelength such as 8.8-nm may be a better choice, Dunne noted.

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2010

SPIE Photomask Technology

13-16 September
Monterey Marriott and
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Late submissions will be considered by Chairs.

2011

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